THE NATURE OF THE IRAS RING G159.6-18.5 IN PERSEUS AND ITS EXCITING STAR HD 278942

B-G ANDERSSON[1,2]
Center for Astrophysical Sciences, Johns Hopkins University, 3400 N. Charles St., Baltimore, MD 21218, bg@pha.jhu.edu
P.G. WANNIER[1]
Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, peter.wannier@jpl.nasa.gov
G.H. MORIARTY-SCHIEVEN[3,4]
Joint Astronomy Centre, 660 N. A'ohōkū Place, Hilo, HI 96720, gms@jach.hawaii.edu
AND
E.J. BAKKER[1,5]
Dept. of Astronomy, University of Texas at Austin, e.j.bakker@fel.tno.nl

Draft version November 15, 1999

ABSTRACT

We discuss an extended feature in the Perseus molecular cloud complex, most prominent in the IRAS database as an almost complete ring of radius 0.75°, but also clearly seen in optical surveys and in radio continuum emission. While earlier identified as a SNR, we argue that the feature is probably an H II region, based on new interferometric radio continuum data at 408 MHz and 1420 MHz, diffuse Hα emission and the identification of HD 278942 as an O9.5-B0V star located at the geometric center of the IRAS ring. The spectral index of the radio continuum emission is consistent with an optically thin H II region. However, an origin of the radio continuum emission, at least partially, as due to synchrotron emission from the interaction region between the stellar wind and the remaining molecular cloud, can not be ruled out. We present visual photometry, spectroscopy and polarimetry of the star HD 278942 (=$AG+31°346$) which we believe to be the source of the excitation for the H II region and the stellar wind. While coincident with an IRAS point source, no compact radio continuum source is seen at the location of the star. Null results for CO (J=1-0) emission different from the ambient cloud, are reported. The possibility that HD 278942 is a main sequence star with a circumstellar disk is suggested.

Subject headings: ISM: individual (Perseus, G159.6-18.5), stars: formation, H II regions

1. INTRODUCTION

An almost complete ring of enhanced emission can be seen in the IRAS 100μm data towards the Perseus molecular cloud complex (figure 1). This was first described by Pauls & Schwartz (1989) and further discussed by Fiedler et al.(1994). These authors argue based on radio data that the feature is due to a supernova remnant (SNR), which would in such a case have the highest known galactic latitude. Recently, de Zeeuw et al (1999) have associated the IRAS ring with the star HD 278942 (=AG+31°346=HIP 17113). Here we expand on this identification and analyze several new data sets, bearing on the star-cloud interaction.

The Perseus molecular cloud complex, at a distance of 260pc (Černis , 1993), has a mass of about 1.3x10^4 $M_\odot$ based on an assumed distance of 260pc (Cernicharo, Bachiller & Duvert, 1985). A generally ordered magnetic field permeates the cloud complex, running along the major axis of the complex, as can be deduced from optical polarimetry of background stars (Goodman et al., 1990; Wannier & Andersson, 1996). Goodman et al. (1989) used Zeeman splitting measurements in the OH lambda-doublet transitions at 1665 and 1667 MHz to derive a line of sight component of the magnetic field of -27$\pm$4 μG. Since the cloud geometry and optical polarimetry indicate that the magnetic field is probably oriented close to the plane of the sky, the true magnetic field strength is likely significantly in excess of this value. Star formation is taking place in several parts of the complex, most obviously around the two reflection nebulae IC 348 and NGC 1333. However, Ladd, Lada & Meyers (1992) surveyed the entire complex for 2μm sources and found pre-main sequence sources throughout the cloud. The regions of intense star formation, IC 348 and NGC 1333, have been respectively observed at near infrared wavelengths by Lada & Lada (1995) and Aspin, Sandell & Russell (1994), and at X-ray wavelengths by Preibisch, Zinnecker & Harbig (1996) and Preibisch, (1997), respectively. A large number of pre- and main sequence stars have been detected by these surveys. However, relatively few high-mass stars have been found in these young clusters. The interaction of newly formed stars with the parent cloud, particularly in the case of massive stars, can have significant consequences for the subsequent development of the cloud. Hot, massive stars cause cloud disruption both through their ionizing flux as well as the momentum in their stellar winds. On the other hand, given the right conditions in the cloud, their stellar winds can also cause collapse of cloud cores and induce further star formation (Foster & Boss, 1996). Hence, the development of an embedded O/B star is an

[1]Visiting Astronomer, McDonald Observatory, University of Texas, Austin.
[2]Guest Observer, Table Mountain Observatory, Jet Propulsion Laboratory.
[3]Guest Observer, National Radio Astronomy Observatory
[4]Guest Observer, James Clark Maxwell Telescope
[5]Current address: TNO-Physics and Electronic Lab., P.O. Box 96864, 2509 JG,, The Haag, The Netherlands

important chapter in the star formation history of the Perseus complex.

2. OBSERVATIONS AND DATA REDUCTION

The present paper is based on a range of observations including radio, mm-wave, infrared and optical. Most of the observations are presented elsewhere so we discuss, in detail, only those not covered in other papers. We have also made use of data in the public domain such as POSS-II, and star count data by Cernicharo & Bachiller (1984).

2.1. *Radio Observations*

The radio continuum observations were acquired with the synthesis telescope (ST) at the Dominion Radio Astrophysical Observatory[6] (DRAO), Penticton, Canada, during 1994 January and March. The observing and data reduction are discussed in detail by Wannier et al. (2000), with the differences that single-dish low-order spacing data (i.e. baselines <12m) were not added to the continuum maps, and that the continuum maps were cleaned and self-calibrated before being combined into a mosaic. For the present purpose we note that the ST samples almost the entire u-v plane (from 12m to 600m) and hence is sensitive to small spatial scales down to the resolution of the array ($\sim 6.5' \times 3.3'$ for the 408 MHz map and $\sim 3.75' \times 2'$ for the 1420 MHz map with the position angle of the major axis oriented north-south). However, due to the missing short spacings, the flux from diffuse emission could potentially be under estimated. The data have (1σ) sensitivity limits of 3.3 mJy/beam (408 MHz) and 0.23 mJy/beam (1420 MHz) at the map center.

2.2. *mm-wave Observations*

Observations of ^{12}CO (J=2-1) and ^{13}CO (J=1-0) were acquired with the NRAO[7] 12m telescope on Kitt Peak, Arizona during, 1996 December 6-11. Dual polarization SIS receivers yielded system temperatures on the sky of about 250K for ^{13}CO 1-0, and 750K for ^{12}CO 2-1. A hybrid autocorrelator spectrometer was used with a maximum spectral resolution of 48kHz. The data were taken in frequency switching mode, switching by ±2 MHz to ±4 MHz. We mapped a 1.8' × 1.8' region in ^{12}CO (2-1) plus a 2.9' × 2.9' region in ^{13}CO (1-0) centered on the location of HD 278942, as well as two cuts across the intensity enhancement in the north and west limbs of the IRAS ring. After folding the frequency switched spectra and averaging the two polarizations, the typical σ_{RMS} per channel was 0.4K and 0.1K for ^{12}CO (2-1) and ^{13}CO (1-0) respectively.

2.3. *850μm Continuum Observation*

Sub-mm wave photometry was acquired at the James Clark Maxwell Telescope[8] on Mauna Kea, Hawaii on 1997, August 22. We used the SCUBA array in photometry mode, following a standard observing procedure in which the source is averaged over an area somewhat larger than the primary beam, by jiggling in a 9 point pattern, while simultaneously chopping the secondary mirror (Ivison et al., 1998). At 850 μm has a beamwidth of 14.5" and for these observations a chop throw of 60" was used. We did not detect any point source associated with HD 278942. After a total integration time of 48 minutes a 3σ upper limit of 7.3mJy was achieved

2.4. *IRAS Data*

IRAS data were extracted in the "FRESCO" mode from the IRAS data base at IPAC[9]. This calibrated data product are co-added and de-striped and represent the full resolution data, without any resolution enhancement techniques or smoothing. We used the algorithms of Kuiper et al. (1987) to derive dust temperatures and optical depths based on the 60μm and 100μm bands. Since the 60μm-to-100μm flux ratio is between 0.3 and 0.9 we use the approximations T_2 and N_2 (see Kuiper et al.) as temperature and column density measures with the modification that we use the more direct measure of dust opacity rather than assuming a gas-to-dust ratio and quoting column density of gas.

2.5. *Visual Wavelength Observations*

Photometry of HD 278942 was acquired at the Table Mountain Observatory during the night of 1995, November 28 using the 24" telescope and a Thompson 512x512 CCD, with a pixel size of 0.5" on the sky. The B and V filters of the Johnson system were used. Due to the low blue sensitivity of the CCD, the U filter was not observed. Several (8) HR catalogue stars were used as standards, taking care to cover a variety of intrinsic colors as well as different air masses throughout the night. The data were reduced using the IRAF PHOTCAL package, after the standard CCD corrections (bias, dark & flatfield) had been performed. Although the night was of only marginal photometric quality with average seeing of ≈ 3", the reduction, including sky correction, converged and produced satisfactory results.

Polarimetry measurements of HD 278942 were acquired with the photopolarimeter (Breger, 1979) on the 82" (2.1m) telescope at McDonald observatory, during the nights of 1994, October 2-5. For HD 278942 measurements were made in the BVR and I filters of the extended Johnson system using a single aperture of 14.73". The details of the observing and data reduction are discussed in Andersson & Wannier (1996).

Echelle spectra of HD 278942 were acquired at the 107" (2.7m) telescope of McDonald observatory during the night of 1996, December 19, using the coudé spectrograph (Tull et al., 1995) and a Tektronix 2048x2048 CCD. The spectra covered wavelengths between 3820Åand 10750Å, with continuous coverage of the region 3850-5000Å. Wavelength calibration was achieved by observing a Th-Ar hollow cathode lamp at several times during the observations. The spectral resolution was measured to be $R \approx 50,000$. Data reduction was performed with standard IRAF procedures and the Echelle orders extracted into 1-dimensional spectra. After normalization, the individual orders were combined to form a continuous one-dimensional spectrum, which was used for the stellar spectral classification. For detailed analysis, such as the C_2 measurements, smaller pieces of the spectrum were extracted.

[6]The Dominion Radio Astrophysical Observatory is operated as a national facility by the Herzberg Institute for Astrophysics of the National Research Council of Canada.

[7]The National Radio Astronomy Observatory is a facility of the National Science Foundation, operated under cooperative agreement by Associated Universities, Inc.

[8]The JCMT is operated by the Royal Observatory Edinburgh on behalf of the Particle Physics and Astronomy Research Council of the United Kingdom, the Netherlands Organization for Scientific Research, and the National Research Council of Canada.

[9]IPAC if funded by NASA as part of the extended IRAS mission under contract to JPL

3. RESULTS

3.1. *Radio Continuum Maps*

At both 408 MHz and 1420 MHz faint extended emission is seen inside the IRAS ring (figure 2). As always, a large number of radio continuum sources can also be seen in the maps. In tables 1 and 2 we list the brightest sources within a few degrees of the star. For 408 MHz, sources with integrated intensities brighter than 0.3Jy are listed, while for 1420 MHz we chose a cutoff of 30 mJy. We provide these tables here as they may be useful as source lists for absorption line studies of the cloud complex. A weak 21cm continuum source (9.7±0.6 mJy) is located 2.4' from the optical position of HD 278942. Given that the offsets between radio and optical coordinates are usually significantly smaller than this (e.g. Riley, 1989), and given the large number of radio continuum sources in the field, we do not feel that this source can be reliably associated with the star. The extended emission, however, is associated with the IRAS ring, as can be seen from figure 2 where, for clarity, we have overlaid the outline of the 100μm ring as the dashed white curve.

We used a point source subtracted map to derive the intensities for this emission, excluding a small region around the brightest 408 MHz source (# 1), due to the imperfect subtraction of this source. An irregular polygon was constructed in the images inside of which the flux was integrated. We find integrated fluxes of 2.0 Jy for the 408 MHz band and 1.4 Jy for the 1420 MHz band, with integration uncertainties of about 0.1 Jy in either band. Because no short spacings were included in the map synthesis the uncertainties for these numbers are highly asymmetrical. We can estimate the amount of flux missing due to the incomplete sampling of the (u,v)-plane based on interferometry theory (e.g. Folamont, 1989). If we assume a uniform source of 30'x30' extent, we find that for 1420 MHz, up to about 3/4 of the total flux may be missing while for 408 MHz, only up to about 1/4 of the flux should be missing. This then yields flux estimates of F(408 MHz)= $2.0^{+0.8}_{-0.1}$ Jy and F(1420 MHz)= $1.4^{+4.3}_{-0.1}$ Jy which in turn yields a spectral index ($F(\nu) \propto \nu^{\alpha}$) of $\alpha = -0.3^{+0.3}_{-1.1}$. This value is consistent with that for an optically thin H II region ($\alpha = 0$), albeit with large uncertainties. We suspect that, whereas we are influenced by missing short spacings, earlier studies (e.g. Fiedler et al., 1994) which have shown more positive spectral indices, may have been misled by the inability to resolve the diffuse source from one or more of the discreet sources. In particular our source #1 (=3C92), with integrated fluxes at 408 MHz and 1420 MHz of 4.5 Jy and 1.4 Jy respectively, and a spectral index of -0.93 could be a problem. We note, however, that Pauls (1999) using VLA (327 MHz) and Effelsberg (2700 MHz) data find a spectral index of $\alpha = -0.9$. Although his two radio data sets were not taken at the same frequency and hence no short spacing data were included in his VLA analysis, the possibility that the diffuse source is of a non-thermal nature can not be ruled out.

3.2. *CO Maps*

The CO maps are dominated by the diffuse CO emission from the Perseus molecular cloud. Although some spatial variation occurs near HD 278942, none can be clearly attributed to the star or to possible circumstellar material (figure 3). Specifically, the spectra directly towards the star do not show any line wings at a level of 0.5K in the ^{12}CO (J=2-1) data and 0.1K in the ^{13}CO (J=1-0) data. Also the cuts across the IRAS ring are dominated by ambient material and show no discernible enhancement at the location of the ring.

3.3. *The IRAS ring*

In figure 4 we show maps of T_{dust} and τ_{dust} for the area of the IRAS ring. As can be seen there is a depression in the opacity of dust towards and to the NW of HD 278942. The observed IRAS ring shows up as an increase in dust optical depth. The temperature map shows that the ring is at a temperature minimum of ≈24K and the dust towards the immediate surrounding of the star is at higher temperatures.

The IRAS point source catalog (PSC) shows a weak source at the center of the extended structure coinciding with the star. We have re-derived the photometry towards the central, compact source, based on the FRESCO data, by "on-chip" photometry. Because the shape and size of the compact source vary rather dramatically from 12μm to 100μm we used only a single aperture in IRAF-APPHOT with a radius of 2.25' and an annulus between 3.75' and 5' for the background subtraction. We chose this aperture as it closely matches the beam size of the 100μm channel. In table 3 we list our derived fluxes for the compact source as well as those from the PSC. We note that although the derived IRAS fluxes depend on the size of the aperture, the colors are close to constant for apertures at least as large as r=5.75'. The uncertainties quoted in table 3 for the four IRAS bands have been increased over the formal errors in the photometry. In order to account for the high and varying background we multiplied the formal (Poisson) errors by the ratio of the average, background subtracted, pixel value inside the aperture and the average pixel value in the sky annulus. In figure 5 we show a black body fit to the data points. As can be seen, the data can be well described by a Planck function of T=65±2K.

3.4. *Diffuse Visible Light Image and Star Counts*

In figure 6 we show an $1.5 \times 1.5°$ image extracted from the POSS-II, using the digital sky survey (DSS) archive at STScI[10]. Contours for the dust opacity have been overlaid to show the relative location of the features. The optical figure consists of a mosaic of 9 subfields from the DSS, a few of which were scaled by up to 15% to avoid high contrast steps between the sub-fields. The strong brightness enhancement in the eastern end of the image is due to the open cluster and reflection nebula IC 348. As can be seen, an irregular region of diffuse emission exists around, and to the NW of HD 278942 (upon which the image is centered) together with several patches of higher opacity material. Comparing to the IRAS data we see that the diffuse emission coincides with the area of lower dust opacity. Several of the features in the diffuse image can be correlated with the star counts of Cernicharo & Bachiller (1984). Most prominently, the dark lane running diagonally from directly north of HD 278942 and to the SE, and then due eastward, shows up as a region of enhanced visual extinction in the star count data. However, neither the location of the star nor the IRAS ring show

[10]The Digitized Sky Surveys were produced at the Space Telescope Science Institute under U.S. Government grant NAG W-2166. The images of these surveys are based on photographic data obtained using the Oschin Schmidt Telescope on Palomar Mountain and the UK Schmidt Telescope. The plates were processed into the present compressed digital form with the permission of these institutions. The Second Palomar Observatory Sky Survey (POSS-II) was made by the California Institute of Technology with funds from the National Science Foundation, the National Geographic Society, the Sloan Foundation, the Samuel Oschin Foundation, and the Eastman Kodak Corporation.

any increase in extinction in the star count data. A decrease is seen in the region of low $100\mu m$ opacity. The star counts in the immediate vicinity of HD 278942 yield a visual extinction of only about 2.5mag.

3.5. *The Star HD 278942*

We have performed spectroscopy, photometry and polarimetry of the star HD 278942 (=$AG+31°346 = BD+31°629$). Our results are summarized in table 4.

3.5.1. *Visual Spectroscopy*

The visual wavelength spectroscopic data allows a spectral classification to be made as well as several interstellar species to be measured (figure 7). In table 5 we have listed the equivalent widths of some of the lines most sensitive to variations in spectral class of late O stars and early B stars. As can be seen, a spectral class between O9 and B0 is most consistent with the measurements. The non-detection of He II would indicate that B0 is the more appropriate classification.

Based on the equivalent width of the $H\gamma$ line (Millward & Walker, 1985), $W_{H\gamma} = 2.5 \pm 0.1$, we find an absolute magnitude of $M_V = -4.9 \pm 0.1$. This is somewhat bright for a main sequence B0 star, which more typically have $M_V \approx -4.0$ (Schmidt-Kaler, 1982). However, preliminary analysis using line synthesis techniques (Fullerton, 1999) shows significant discrepancies between the observed Hα and Hβ lines, and models of B giant atmospheres, indicating a higher surface gravity than for giants. We hence assign a preliminary spectral class of O9.5-B0V, while noting the above inconsistencies. We defer detailed modeling of the stellar spectrum to a later paper.

If we use the derived luminosity and surface gravity to indicate the earlier spectral class of O9.5V, we may use the stellar evolution tracks from Shaller et al., (1992) to derive a stellar age. Assuming a solar metallicity we find an age of about 8 Myrs. This estimate is similar to the estimated age of the PerOB2 association (Giménez & Clausen, 1994), while somewhat older than the estimated age of the nearby open cluster IC 348 (Herbig, 1998).

Based on the Si III triplet at $\lambda\lambda 4552.6, 4567.8$ & 4574.8Å we find a LSR velocity for the star of $v_{LSR} = 28 \pm 1$ $km\ s^{-1}$, which may be compared to the interstellar absorption velocities of $v_{LSR} = 8$ $km\ s^{-1}$ for CH(λ4300) and C_2(Q(2);λ8761) and $v_{LSR} = 6$ $km\ s^{-1}$ for Ca II and Na I. The mm-wave CO emission in the direction of the star is centered at about 7 $km\ s^{-1}$. Finally, using the FWHM of He I lines at λ4026Å & λ4388Å (the line at 4471Å was excluded due to severe blending) and their relation to rotational velocity (Gray, 1992) we find $v \sin i = 125 \pm 20$ $km\ s^{-1}$.

3.5.2. *Photometry*

From the photometric measurements we find a V magnitude of 8.83 ± 0.01 and a B magnitude of 10.27 ± 0.01. For comparison Černis (1993) found $V = 9.10 \pm 0.012$. If we use the relation between colors in the Vilnius system and (B-V) (Straižys, 1992)

$$B - V = -0.33 + 0.50\{(X - V) + (Y - V)\} \qquad (1)$$

we find that Černis' results corresponds to $B = 10.44$. Černis (1997) reports having detected no variability for the star in his set of 4 separate measurements between 1985 and 1991. We note that our application of equ. (1) is in a range outside of the stated validity range of B-V<0.8. The derived spectral class yields an intrinsic color of $(B-V)_0$= -0.30±0.01 (Straižys, 1992) and hence a color excess of $E_{B-V} = 1.75$.

3.6. *Interstellar polarization and absorption towards HD 278942*

Several interstellar atomic and molecular lines were detected in the spectrum of HD 278942, including those of Na I, Ca II, CH and CH^+. Here we will concentrate solely on the measurements of the C_2 Phillips band at $\lambda\lambda 8757-8782$Å, since these lines allow us to derive an estimate of the kinetic temperature of the intervening gas. In figure 8 we show the C_2 spectrum against the background of the Paschen ι line of the star. In table 6 we list the measurements and derived values for the C_2 observations, assuming a b-value of 1.0 km s^{-1}. In those cases where two C_2 lines are blended, e.g. R(4) and R(8), we performed constrained fits of the spectrum, imposing the measured wavelength separation of the lines and a common line width.

The excitation in the electronic ground state of C_2 is influenced by the strength of the infrared radiation field, through the fluorescence between the $X^1\Sigma_g^+$ and the $A^1\Pi_u$ states (van Dishoeck & Black, 1982). Therefore, the detailed interpretation of the level populations of the rotational ladder is somewhat model dependent through the factor $n\sigma/I_{IR}$, where n is the density of collision partners, σ is the collision cross section and I_{IR} is the local infrared radiation field (see van Dishoeck & Black (1982) for details). However, we can form two estimates of the kinetic temperature in the gas. The simplest consists of the direct excitation temperature between the J=2 and J=0 levels, for which we derive an excitation temperature of 26±5K. A more complete analysis (c.f. Federman et al., 1994) yields a best fit for all the measured level populations of T=20±10K and $n\sigma/I_{IR} = (7 \pm 2) \times 10^{-14}$. For a cross section of 2×10^{-16} (van Dishoeck and Black, 1982) this corresponds to n/I_{IR}=350 cm^{-3}. Given that the infrared radiation field of the region is likely to be higher than normal, n=350 cm^{-3} must be viewed as a lower limit to the actual space density of the C_2 bearing gas.

3.6.1. *Polarimetry*

The polarization measurements show a polarization curve that increases monotonically from B to I band (figure 9), while flattening off towards the infrared. The angle of polarization stays constant to within the measurement uncertainties. The R-band polarization of 5.9 ± 0.03%, at an angle of $154.0 \pm 0.2°$ (E of N) is consistent, both in magnitude and in direction, with the most highly polarized sources in the Perseus complex, as measured by Goodman et al. (1990), as well as the (red) polarization of BD+31°643 (Andersson & Wannier, 1997).

The maximum of the polarization curve has been shown to be related to R, the ratio of total-to-selective extinction (Whittet and van Breda, 1987). We therefore used the Serkowski relation (e.g. Whittet, 1992) to find the wavelength of maximum polarization. The formally best solution yields $\lambda_{max} = 0.76 \pm 0.01\mu m$. The uncertainty in this value is only from the formal fitting uncertainty. The true values of both λ_{max} and $\sigma_{\lambda_{max}}$ are likely to be larger, since we do not have any near infrared data and the observed polarization curve does not conform well to a standard Serkowski shape. Using the relationship between λ_{max} and R from Whittet and van Breda (1987) we find $R = 4.3 \pm 0.2$.

4. DISCUSSION

4.1. *The Physical Nature of the IRAS Ring and its Surroundings*

4.1.1. *The IRAS ring and its origin*

We used the maps of the 4 IRAS bands to compare the location of the diffuse FIR emission and that of HD 278942. From IRAS ratio maps we extracted 1-dimensional cuts in the four canonical directions. In each case, the center of the IRAS ring fell within 5' of the map center (location of HD 278942). Hence the geometry of the IRAS ring and the location of the star HD 278942 strongly indicate that the latter is responsible for the former. The fact that the ring observationally is due to an opacity enhancement and is filled by warm dust indicates that it is the result of an expanding stellar wind. The identification of HD 278942 as an O9.5-B0V star at the ring's geometric center supports this conclusion in that stars of this type are known to have fast stellar winds with mass loss rates of the order of $10^{-7} M_{\odot}$/yr (Lamers, & Leitherer, 1993; and ref.s therein).

4.1.2. *The diffuse emission and its excitation*

The flat spectrum of the diffuse radio source suggests that the emission is due to optically thin thermal radiation. As can be seen from figure 6 the diffuse Hα emission closely coincides with the low dust-opacity region in the western part of the IRAS maps and lower surface intensity emission can be seen to the NW of the brightest part. A comparison with published large scale CO maps of the region (e.g. Cernicharo & Bachiller, 1986) shows that the star is located close to the ^{13}CO edge of the cloud at a place where the local CO gradient is oriented in a roughly E-to-SE direction. Another interesting comparison can be made to the maps of H I (21 cm) emission from Wannier et al. (2000). Figure 10 shows a single channel map of H I (21 cm) emission at v_{LSR}=10 km s^{-1} in which we have also marked the approximate location of HD 278942. This velocity corresponds to the center velocity of the molecular gas in the B5 region (at the easternmost extent of the Perseus complex), while it is somewhat redder than the CO velocity at the location of B1 (Ungerechts & Thaddeus, 1987; Wannier et al., 2000). Immediately to the North-West of the IRAS ring a pincer-like feature can be seen in the atomic hydrogen emission. These H I observations suggest that the H II region around HD 278942 has broken through the cloud to the NW and is venting its ionized gas into the low density surroundings. The dark patches seen in the optical image and the star count data would suggest that the center of the blister is located somewhat behind the mid plane of the cloud, a view supported by the kinematics of large scale H I observations of the region (Wannier et al., 2000).

The diffuse radio continuum emission is clearly strongest in the eastern part of the IRAS ring. Given the combined data sets, we feel that the most natural interpretation of the measured radio fluxes is that we have somewhat more missing flux in our higher-frequency 1420 MHz data than in our 408 MHz data, and that the spectral index is indicative of an optically thin H II region. The distribution of the diffuse radio emission can then be understood as the continued interaction of the stellar UV radiation with the remaining parent cloud. However, our data are also consistent with a spectral energy distribution rising at longer wavelengths, indicating a possible non-thermal component (c.f. Pauls, 1999). We will not explore this second possibility in detail here, but note in passing that in a strong stellar wind, some non-thermal emission is possible due to interaction of the wind with the remaining molecular cloud, or from shocks within the wind (White (1985) ; Bieging, Abbott & Churchwell, 1989). Whether such a mechanism would be able to produce the observed radiation is unclear and will require a more complete analysis of all the available radio data.

4.2. *The Star and its Immediate Surroundings*

The high color excess of the star indicates heavy obscuration. Using the derived R value of 4.3, a visual extinction of $A_V = 7.4\ mag.$ is found. Since Perseus is the only major source of extinction in the direction (Černis, 1993), and recognizing the non-standard shape of the polarization curve from which R was derived, we may turn the argument around and ask what value of R is found from the measured colors and assuming the star to be at the distance of the Perseus complex (260pc; Ćernis, 1993). We note that the Hipparcos datum for the star; 207$\pm$52 pc (ESA, 1997) is consistent with the photometric distance. With this distance estimate and $M_V = -4.9\ mag.$, we find R=3.8 ($A_V = 6.7$). Considering the uncertainty in the fit for λ_{max} , this is quite good agreement. We may therefore safely conclude that HD 278942 is indeed located within the Perseus molecular cloud.

The large scale extinction, as measured by star counts, shows a significantly lower value towards the star. Even though star counts can severely under estimate the average extinction in a patchy region, the existence of a strong compact source in the shorter IRAS bands at the location of the star would seem to indicate a circumstellar term in the visual extinction besides the diffuse contributions.

4.2.1. *A Possible Circumstellar Disk*

A high degree of linear polarization suggests a non-isotropic geometry for the source (e.g. Bastien & Ménard, 1990). The recent detection of a dust disk around the B5V star $BD+31°643$ in IC 348, makes the polarization measurements of HD 278942, taken together with the IRAS and mm-wave data, extra intriguing as an indicator of a possible circumstellar disk. In the case of BD+31°643 aperture polarimetry shows a polarization which is parallel to the major axis of the projected disk and is perpendicular on the sky to the projected direction of the local magnetic field (Andersson & Wannier, 1997). The magnetic field in the vicinity of HD 278942 seems, based on polarization measurements in the cloud halo (Wannier & Andersson, 1996), to be similarly directed along the long axis of the cloud complex. As for BD+31°643, the polarization of HD 278942 is perpendicular to this field direction. That our IRAS photometry yields quite a good fit to a 65K blackbody, indicates the presence of heated dust around the star. The fact that no circumstellar CO emission is detected, as well as the significantly lower excitation temperature of C_2, compared with the dust, in turn indicates the possibility of a circumstellar dust disk, rather than a gaseous circumstellar envelope. The recent discovery of a circumstellar disk around the embedded O9 star G339.88-1.26 by Stecklum et al. (1998), lends added credence to this hypothesis. Hence, we suggest that the high mass, main sequence star, HD 278942 may have a circumstellar disk.

5. CONCLUSION

We have shown that the star HD 278942 is a heavily obscured O9.5-B0V star located at the geometric center of the IRAS ring G159.6-18.5. Based on spectroscopy, photometry and polarimetry, we argue that this superposition is not accidental, but that the star is embedded in the Perseus molecular cloud and is indeed responsible for the IRAS feature. A faint, flat spectrum extended radio source is found at the location of the IRAS ring as well as diffuse $H\alpha$ emission at and to the NW of the star. The extent of the latter coincides with a depression in the 100μm opacity and we interpret this as the result of a ruptured H II blister, i.e. an H II region expanding past the boundary of the enclosing cloud. An intriguing possibility, suggested by the direction of the polarization vectors and the IRAS point source measurements, is that HD 278942 has a circumstellar disk, similar to that recently detected around $BD+31°643$ (Kalas &Jewitt, 1997; Andersson & Wannier, 1997).

It is a pleasure to acknowledge the staffs at each of the observatories used for this study for their skilled and generous support. We gratefully acknowledge Drs. A.W. Fullerton and S.R. Federman for helpful discussions and the use of their analysis routines. The referee, Dr. T. Pauls, provided several helpful comments and suggestions. This work was, in part, carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

REFERENCES

Andersson, B-G and Wannier, P.G., 1996, ApJ, 443, L49.
Andersson, B-G and Wannier, P.G., 1997, ApJ, 491, L103.
Aspin, C, Sandell, G. and Russell, A.P.G., 1994, A&AS, 106, 165.
Bastien, P. & Ménard, F., 1990, ApJ, 364, 232.
Beiging, J.H., Abbott, D.C. and Churchwell, 1989, ApJ, 340, 518.
Breger, M., 1979, ApJ, 233, 97.
Cernicharo, J. and Bachiller, R., 1984, A&AS, 58, 327.
Cernicharo, J. and Bachiller, R., 1986, A&A, 166, 283.
Cernicharo, J., Bachiller, R. and Duvert, G., 1985, A&A, 149, 273.
Černis, K., 1993, Balt. Astr., 2, 214.
Černis, K., 1997, private communication
Conti, P.S., 1973, ApJ, 179, 161.
de Zeeuw, P.T., Hoogerwerf, R., Bruijne, J.H.J., Brown, A.G.A. and Blaauw, A., 1999, AJ, 117, 354.
Didelon, P., 1982, A&AS, 50, 199.
Federman, S.R., Strom, C.J., Lambert, D.L., Cardelli, J.A., Smith, V.V. and Joseph, C.L., 1994, ApJ, 424, 772.
Fiedler, R, Pauls, T., Johnston, K.J. and Dennison, B., 1994, ApJ, 340, 595.
Folamont, E.B., 1989, in "Synthesis Imaging in Radio Astronomy", Perley, R.A., Schwab, F.R. & Bridle, A.H., eds., ASP conf. ser., no. 5.
Fullerton, A.W., 1999, private communication.
Foster, P.N. and Boss, A.P., 1996, ApJ, 468, 784.
Giménez, A. and Clausen, J.V., 1994, A&A, 291, 795
Goodman, A.A., Crutcher, R.M., Heiles, C., Myers, P.C. and Troland, T.H., 1989, ApJ, 338, L61.
Goodman, A.A., Bastien, P., Meyers, P.C. and Ménard, F., 1990, ApJ, 359, 363.
Gray, D.F., 1992, "The Observation and Analysis of Stellar Photospheres", (Cambridge: Cambridge UP), p.378.
Herbig, G.H., 1998, ApJ, 497, 736.
ESA. 1997, The Hipparcos and Tycho Catalogues (ESA SP-1200) (Noordwijk: ESA)
Ivison, R. J., Dunlop, J. S., Hughes, D. H., Archibald, E. N., Stevens, J. A., Holland, W. S., Robson, E. I., Eales, S. A., Rawlings, S., Dey, A. and Gear, W. K., 1998, ApJ, 494, 211.
Jaschek, C. and Jaschek, M., 1987, "The Classification of Stars", (Cambridge: Cambridge UP), p137.
Kalas, P. and Jewitt, D., 1997, Nature, 386, 52.
Kuiper, T.B.H., Whiteoak, J.B., Fowler, J.W. and Rice, W., 1987, MNRAS, 227, 1013.
Ladd, E.F., Lada, E.A. and Meyers, P.C., 1992, ApJ, 410, 168.
Lada, E.A., and Lada, C.J., 1995, AJ, 109, 1682.
Lamers, H.J.G.L.M. and Leitherer, C., 1993, ApJ, 412, 771.
Millward, C.G. and Walker, G.A.H., 1985, ApJS, 57, 63.
Pauls, T. and Schwartz, P.R., 1989, in "The Physics and Chemistry of Interstellar Molecular Clouds", G. Winnewisser and T.J. Armstrong, eds. Lecture Notes in Physics, vol 331, (Berlin: Springer) p. 225. Tool for Astrophysical Insight", P.A.S.P. Conf. Series, Vol. 60, p325
Pauls, T.,1999, AAS, 194.4704
Peterson, D.M. and Scholz, M., 1971, ApJ, 163, 51.
Preibisch, Th.,Zinnecker, H. and Herbig, G.H., 1996, A&A, 310, 456.
Preibisch, Th., 1997, A&A, 324, 690.
Riley, J.M., 1989, MNRAS, 238, 1055.
Schaller, G, Schaerer, D., Meynet, G. and Meader, 1992, A&AS, 96, 269.
Schmidt-Kaler, T.H., 1982, "Landholt-Bornstein New Series", Vol. 2b, Springer Verlag, New York.
Straižys, V., 1992, "Multicolor Stellar Photometry", (Tucson: Pachart)
Stecklum, B., et al., 1992, ESO Press release 08/98.
Tull, R.G., Macqueen, P.J., Sneden, C. and Lambert, D.L., 1995, PASP, 107, 251.
Ungerechts, H. and Thaddeus, P., 1987, ApJS, 63, 645.
van Dishoeck, E.F. and Black, J.H., 1982, ApJ, 258, 533.
Wannier, P.G. & Andersson, B-G, 1996, in "Polarimetry of the Interstellar Medium", Roberger, W.G. and Whittet, D.C.B., eds. P.A.S.P. Conf. Series, Vol. 97, p522.
Wannier, P.G., Moriarty-Schieven, G. and Andersson, B-G, Hilts, M., & Langer, W.D., 2000, in preparation.
White, R.L., 1985, ApJ, 289, 698.
Whittet, D.C.B., 1992, "Dust in the Galactic Environment" (Bristol: IoP Publishing), p93.
Whittet, D.C.B. and van Breda, I.G., 1987, A&A, 66, 57.

TABLE 1
408 MHz SOURCES

Source	R.A. (2000)	±	Dec. (2000)	±	Int. Flux [mJy]	Peak Flux [mJy]	Size	P.A. N of E
5	$3^h34^m17.01^s$	0.14^s	31° 12' 05.9"	2.7"	677.5±27.4	(677.8±22.8)		
11	$3^h35^m04.52^s$	0.15^s	30° 47' 20.9"	2.4"	421.5±16.2	(375.8 ±12.4)		
3	$3^h36^m29.91^s$	0.11^s	32° 18' 24.7"	1.4"	2126.8 ±67.2	(2127.5 ±64.9)		
4	$3^h36^m59.29^s$	0.11^s	31° 44' 06.2"	1.4"	896.4 ±28.5	(896.8 ±27.4)		
16	$3^h37^m43.72^s$		32° 06' 23.8"		488.7 (centroid)			
16 A	$3^h37^m36.20^s$	0.61^s	32° 07' 44.5"	9.7"	184.6 ±23.1	(184.8 ±11.3)		
16 B	$3^h37^m51.16^s$	0.65^s	32° 03' 10.3"	20.2"	220.7 ±25.7	(146.4 ±9.5)	6.9'x0.8'	2°
13	$3^h37^m50.49^s$	0.17^s	31° 14' 51.1"	3.5"	353.3 ±16.0	(322.4 ±11.5)		
7	$3^h37^m51.44^s$	0.15^s	30° 55' 57.6"	3.0"	673.8 ±75.7	(674.0 ±23.5)		
1	$3^h40^m08.28^s$	0.11^s	32° 09' 01.3"	1.3"	4452.1 ±139.2	(4454.2 ±135.4)		
6	$3^h42^m54.40^s$	0.13^s	30° 47' 38.2"	2.2"	683.4 ±25.2	(683.9 ±22.1)		
2	$3^h43^m09.28^s$	0.11^s	31° 15' 13.1"	1.3"	2326.8 ±73.3	(2255.1 ±68.7)		
9	$3^h44^m00.78^s$	0.14^s	31° 38' 15.3"	2.7"	471.7 ±19.2	(471.8 ±15.9)		
10	$3^h44^m10.03^s$	0.14^s	32° 29' 22.8"	2.5"	426.0 ±18.8	(426.1 ±14.3)		
12	$3^h44^m16.96^s$	0.22^s	31° 53' 35.5"	4.1"	387.4 ±35.0	(348.6 ±13.7)		
8	$3^h44^m32.56^s$	0.13^s	32° 12' 39.9"	2.2"	753.5 ±27.2	(632.6 ±20.3)		

TABLE 2
1420 MHz SOURCES

Source	R.A. (2000)	±	Dec. (2000)	±	Int. Flux [mJy]	Peak Flux [mJy]	Size	P.A. N of E
3	$3^h37^m37.14^s$	0.10^s	32° 08' 01.6"	1.1"	82.7±2.7	77.8±2.4	0.5'x0.2'	174°
2	$3^h37^m49.78^s$	0.10^s	31° 15' 13.1"	1.0"	124.7±4.0	124.7±3.8		
6	$3^h37^m50.76^s$	0.10^s	32° 02' 08.9"	1.1"	45.6±1.6	45.6±1.4		
7	$3^h38^m04.71^s$	0.10^s	31° 36' 29.5"	1.1"	35.7±1.2	35.7±1.1		
9	$3^h38^m33.88^s$	0.10^s	32° 22' 25.4"	1.1"	33.9±1.2	33.9±1.1		
5	$3^h39^m58.94^s$	0.10^s	32° 21' 04.9"	1.1"	49.6±1.6	49.7±1.5		
10	$3^h40^m06.48^s$	0.10^s	31° 28' 24.0"	1.1"	31.5±1.1	31.5±1.0		
1	$3^h40^m08.44^s$		32° 09' 00.5"		1429.2 centroid			
1 A	$3^h40^m08.47^s$	0.13^s	32° 08' 59.3"	2.6"	1416.8±92.2	1217.1±76.7	0.9'x0.0'	22°
1 B	$3^h40^m07.05^s$	1.14^s	32° 09' 46.1"	57.9"	30.3±97.7	29.8±95.9		
4	$3^h41^m31.30^s$	0.10^s	32° 24' 57.7"	1.1"	67.4±2.2	66.7±2.1		
8	$3^h41^m41.07^s$		31° 23' 07.8"		57.2 centroid			
8 A	$3^h41^m40.38^s$	0.39^s	31° 23' 00.8"	5.5"	40.7±6.2	32.1±4.3	0.7'x0.5'	57°
8 B	$3^h41^m43.14^s$	0.50^s	31° 23' 17.5"	19.3"	12.7±6.1	11.8±5.2		
8 C	$3^h41^m40.29^s$	1.37^s	31° 23' 52.4"	11.9"	4.2±3.6	4.2±3.6		
11	$3^h42^m03.46^s$	0.10^s	31° 27' 03.9"	1.2"	34.4±1.4	32.3±1.1		
12	$3^h43^m23.17^s$	0.10^s	31° 36' 40.4"	1.1"	30.3±1.0	30.3±1.0		

TABLE 3
DERIVED FIR FLUXES FOR THE COMPACT SOURCE.

λ [μm]	IRAS PSC [Jy]	FRESCO/JCMT [Jy]
12	0.46±0.03	1.08±3.2
25	1.68±0.20	13.02±2.1
60	<9.56	26.9±1.5
100	<19.25	15.8±2.9
850	...	<0.73

TABLE 4
DERIVED STELLAR PARAMETERS FOR HD 278942.

Spectral Class	O9.5-B0V
m_V	$8.83 \pm 0.01 mag.$[a]
B-V	$1.44 \pm 0.01 mag.$
M_V	-4.9±0.1mag.
E_{B-V}	1.75mag. ($A_V = 5.5 - 7.6 mag.$ for R=3.1-4.3)
v_{LSR}	28 ± 1 $km\ s^{-1}$
$v \sin i$	125 ± 20 $km\ s^{-1}$

[a]Černis (1993) reports $m_V = 9.10 \pm 0.01$ & (B-V)= 1.34 based on Vilnius photometry

TABLE 5

EQUIVALENT WIDTHS FOR HD 278942 AND STANDARDS[a]

Line	HD 278942	O8	O9	B0	B2
$H\alpha$	2.3±0.2	...	...	3.8	6.0
$H\beta$	2.5±0.2	...	...	3.8	6.0
$H\gamma$	2.4±0.3	2.2	2.6	3.5	5.1
He I(λ4471 Å)	0.7±0.1	0.9	1.0	1.0	1.3
He I(λ4026 Å)	0.9±0.1	0.7	0.9	1.0	1.3
He I(λ4388 Å)	0.6±0.1	0.4	0.45	0.8	
He II(λ4541 Å)	< 0.08	0.6	0.4	...	...
Mg II(λ4481 Å)	0.07±0.005	...	...	0.1	0.2
C II(λ4267 Å)	0.08±0.01	...	...	0.05	0.2
Si IV(λ4089 Å)	0.06±0.01	0.3	0.35	0.2	0

[a]From Peterson & Scholz, 1971, Conti (1973), Didelon (1982) and Jaschek & Jaschek, (1987)

TABLE 6
C$_2$ ANALYSIS

Line	λ[a] [Å]	f[b]	W [mÅ]	N[c] [10^{13}cm^{-2}]
R(0)	8757.686	1.0×10^{-3}	13.3±0.3	2.2±0.5
N(0)	...	...	...	**2.2±0.5**
R(2)	8753.949	4.0×10^{-4}	15.0±0.3	6.2±0.2
Q(2)	8761.194	5.0×10^{-4}	17.0±0.4	5.7±0.2
P(2)	8766.031	1.0×10^{-4}	3.9±0.3	5.9±0.5
N(2)	...	...	...	**5.9±0.2**
R(4)	8751.685	3.33×10^{-4}	7.9±0.3	3.7±0.2
Q(4)	8763.751	5.0×10^{-4}	13.8±0.5	4.5±0.2
P(4)	8773.430	1.67×10^{-4}	3.3±0.3	3.0±0.3
N(4)	...	...	...	**3.9±0.6**
R(6)	8750.848	3.08×10^{-4}	3.9±0.2	1.9±0.1
Q(6)	8767.759	5.0×10^{-4}	7.9±0.4	2.5±0.1
P(6)	8782.308	1.92×10^{-4}	3.4±0.2	2.7±0.2
N(6)	...	...	...	**2.3±0.3**
R(8)	8751.486	2.94×10^{-4}	1.7±0.3	0.9±0.2
Q(8)	8773.221	4.99×10^{-4}	5.6±0.5	1.7±0.2
N(8)	...	...	...	**1.3±0.4**
R(10)	8753.578	2.86×10^{-4}	2.5±0.3	1.3±0.2
Q(10)	8780.141	4.99×10^{-4}	2.3±0.3	0.7±0.1
N(10)	...	...	...	**0.8±0.3**
Q(12)	8788.559	4.98×10^{-4}	1.4±0.4	0.4±0.1
N(12)	...	...	...	**0.4±0.1**
Q(14)	8788.559	4.98×10^{-4}	0.9±0.5	0.3±0.2
N(14)	...	...	...	**0.3±0.2**
Q(16)	8788.559	4.97×10^{-4}	1.5±0.3	0.4±0.1
N(16)	...	...	...	**0.4±0.1**

[a]From van Dishoeck and de Zeeuw (1984)

[b]From Federman et al. (1994)

[c]Assuming b=1.0 km s^{-1}

FIG. 1.— A gray scale map of the 100μm emission and a contour map of CO emission in the Perseus molecular provides a "road map" to the IRAS ring feature discussed in the present paper. The ring is the prominent feature centered at about (3:40, +32). We have noted the main features of the complex, including the main sub-clouds as well as the two open clusters IC 348 and NGC 1333. The dashed curve illustrate the approximate extent of the 1420 MHz continuum map discussed in this study.

FIG. 2.— This mosaic of three ST fields of 1420 MHz continuum emission clearly shows the low level diffuse emission due to the H II region responsible for the IRAS ring. In large number of background radio sources can also be see. Note in particular, source #1 (see table 1) which is located close to the diffuse emission. It is only after careful subtraction of these point sources that reliable fluxes can be integrated for the H II region.

FIG. 3.— Grids of a) ^{12}CO (J=2-1) and b) ^{13}CO (J=1-0) spectra in the area of HD 278942 show no obvious contribution from circumstellar material.

FIG. 4.— The opacity and temperature of the IRAS ring region were derived using the algorithms of Kuiper et al (1987). Each panel is a 2° field centered on HD 278942. The left hand panel shows the dust opacity while the right hand panels shows dust temperature. In both cases, brighter gray scale corresponds to larger values. For most of the pixels, the dust opacity varies between 0 and 0.2. The temperature varies between 21 and 31K

FIG. 5.— The results of the "on chip" aperture photometry of source at the location of HD 278942, using the IRAS FRESCO data together with 850μm SCUBA photometry, was fit to a black body function. The best fit yields a temperature of 65$\pm$2K

FIG. 6.— A 1.5 × 1.5° excerpt from the POSS-II, extracted from the digital sky survey (DSS) archive at STScI is shown together with contours for the dust opacity. The image is centered on HD 278942. Note the presence of several patches of high opacity to the east of the star.

FIG. 7.— We observed HD 278942 with the coudé spectrograph at the 2.8m telescope at McDonald observatory. This Echelle spectrum of HD 278942 yields a O9.5-B0V spectral classification. We have used line ratios of a number of tracers to derive the spectral class and some fundamental stellar parameters, such as radial velocity and stellar rotation (see table 4)

FIG. 8.— a) Against the backdrop of the Paschen ι line of the star the interstellar lines from the Philips band of C_2 can be detected up to Q(16). b) After normalizing out the stellar line, the C_2 lines were analyzed to yield a gas temperature of 20$\pm$10K and a space density of $n_H \geq 350$ cm^{-3}.

FIG. 9.— Multiband polarimetry of HD 278942 reveals a non- standard polarization curve, monotonically rising towards the red. The direction of polarization is found to be constant for all four bands at $\theta = 154°$

FIG. 10.— A single channel map of atomic Hydrogen emission from Wannier et al (2000) at v_{LSR}=10 km s^{-1} shows some of the interaction of HD 278942 and its host cloud. Note, in particular, the pincer-like feature to the north-west of the star (see text)